Respiratory Disease Associated with Community Air Pollution and a Steel Mill, Utah Valley

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Abstract: This study assessed the association between hospital admissions and fine particulate pollution (PM_{10}) in Utah Valley during the period April 1985–February 1988. This time period included the closure and reopening of the local steel mill, the primary source of PM_{10}. An association between elevated PM_{10} levels and hospital admissions for pneumonia, pleurisy, bronchitis, and asthma was observed. During months when 24-hour PM_{10} levels exceeded 150 $\mu g/m^3$, average admissions for children nearly tripled; in adults, the increase in admissions was 44 per cent. During months with mean PM_{10} levels greater than or equal to 50 $\mu g/m^3$ average admissions for children and adults increased by 89 and 47 per cent, respectively. During the winter months when the steel mill was open, PM_{10} levels were nearly double the levels experienced during the winter months when the mill was closed. This occurred even though relatively stagnant air was experienced during the winter the mill was closed. Children's admissions were two to three times higher during the winters when the mill was open compared to when it was closed. Regression analysis also revealed that PM_{10} levels were strongly correlated with hospital admissions. They were more strongly correlated with children's admissions than with adult admissions and were more strongly correlated with admissions for bronchitis and asthma than with admissions for pneumonia and pleurisy. (*Am J Public Health* 1989; 79:623–628.)

Introduction

On March 20, 1984, the US Environmental Protection Agency (EPA) proposed changes in the national ambient air quality standards for particulate pollution. Total suspended particulates (TSP) was to be replaced with a new indicator of particulate pollution that includes only those particulates with an aerodynamic diameter equal to or less than a nominal 10 micrometers (PM_{10}). On July 1, 1987, the EPA announced its final decision. The previous primary TSP standards were to be replaced, effective July 31, 1987, with a 24-hour PM_{10} standard of 150 micrograms per cubic meter ($\mu g/m^3$) with no more than one expected exceedance per year and an annual PM_{10} standard of an expected arithmetic mean of 50 $\mu g/m^3$.[1]

Earlier studies of the health effects of particulate pollution[2–8] revealed a possible connection between air pollution and human health, and launched a wave of research exploring this connection.[9–19] Recent research has observed that even moderately elevated concentrations of particulate pollution may result in reductions in children's pulmonary function[20,21] and increased risk for bronchitis and other respiratory illnesses.[22] Other recent research questions the existence of a threshold level.[1,23]

Previous studies have not used PM_{10} as an indicator of particulate pollution. Recent experiences in Utah County have provided a unique opportunity to investigate a possible association between respiratory health and different levels of PM_{10}. Utah Valley has had daily monitoring of PM_{10} since April 1985; it has an extremely low percentage of smokers; it has experienced a prolonged shut-down and then reopening of the steel mill, its largest source of particulate pollution; over time, since monitoring of PM_{10} began, the valley has experienced considerable variability in levels of fine particulate pollution; and hospital inpatient admissions data for respiratory illnesses can be obtained. The objective of this paper is to report what has been observed in Utah Valley with respect to hospital admissions for respiratory illnesses and PM_{10} levels.

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Methods

Study Area

Utah Valley, located in Utah County of Central Utah, is the third largest county in the state with a population of 258,000 in 1987.[24] Approximately two-thirds of the population resides in five nearly contiguous cities situated on a valley floor with an elevation of approximately 1,402 meters above sea level bordered east and west by mountains (Figure 1).

Based on an unpublished 1986 Utah State Department of Health survey, only 5.5 per cent of Utah County's adults (18 years of age or older) smoke; approximately 90 per cent of its

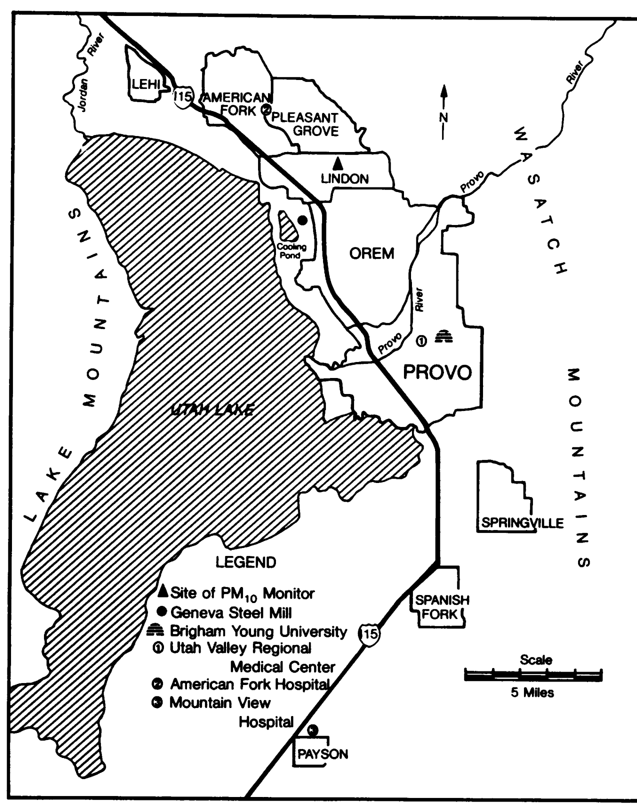

FIGURE 1—Study Area, Utah Valley

residents are members of the Church of Jesus Christ of Latter-Day Saints (Mormon)[25,26] which has strong church teachings against smoking.

Monitoring of particulate pollution began in 1964 and for carbon monoxide in 1971. On March 3, 1978, the EPA designated the county as a non-attainment area in accordance with provisions of Section 107 of the Clean Air Act. EPA ambient air quality standards for TSP and carbon monoxide were often exceeded at monitoring sites at Provo, Lindon, and Pleasant Grove during winter months when temperature inversions trapped emissions in stagnant air near the valley floor.

Generally, the county experienced improvements with respect to carbon monoxide pollution in the 1980s. At one monitoring site, the number of exceedances of the maximum eight-hour primary health standard for carbon monoxide fell from a high of 52 exceedances in 1982 to 10 exceedances in 1985. In order to continue to reduce levels of carbon monoxide pollution in the county, an automobile inspection/maintenance and anti-tampering program was implemented in 1986.

Particulate pollution levels in the county remained about the same from 1979–85. The 24-hour TSP standard of 260 $\mu g/m^3$ was exceeded as many as 10–18 times per year. The average annual geometric mean from 1979–85 for TSP at the Lindon monitor equalled 65 $\mu g/m^3$. This mean level of TSP exceeded EPA's annual secondary standard of 60 $\mu g/m^3$ but not the annual primary health standard of 75 $\mu g/m^3$. Monitoring of sulfur dioxides (SO_2) was conducted in the county in the 1970s but was discontinued because SO_2 levels were substantially below the annual primary health standard of .03 ppm, the 24-hour primary health standard of .14 ppm and the secondary 3-hour standard of .5 ppm.

The primary industrial source of fine particulate pollution as measured by PM_{10} in Utah County is the Geneva steel mill, commonly referred to as Geneva, located near Orem (Figure 1). When in operation, the mill emits approximately 82 per cent of all industrial sources of PM_{10} including power generation.[27] When all sources are accounted for, Geneva's contribution to PM_{10} equals 47 to 80 per cent of total emissions.[27] Other sources of PM_{10} include wood burning (approximately 16 per cent), road dust (approximately 11 per cent), diesel fuel and oil combustion (approximately 7 per cent). Also, Geneva's contribution to the county's industrial emissions of sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxides are approximately 95, 98, 86, and 82 per cent, respectively.[27]

Geneva was built for the US Government in the early 1940s as part of the World War II effort. It was sold to US Steel Corp in 1946. On August 1, 1986, the Geneva steel mill shut down as a result of a labor dispute with USX Corporation (previously US Steel Corp.) The plant reopened on September 1, 1987 under a new owner, Basic Manufacturing and Technologies of Utah, Inc. In April 1985, the Bureau of Air Quality began to daily monitor PM_{10} at a site in Lindon (Figure 1) using a Sierra Anderson high volume sampler. During the winter season of 1985/86, Geneva was still open and 24-hour PM_{10} levels exceeded 150 $\mu g/m^3$ on 13 occasions. The highest single day concentration was 365 $\mu g/m^3$. During the winter of 1986/87 while Geneva was shut down, 24-hour PM_{10} levels never exceeded 150 $\mu g/m^3$. During the winter of 1987/88, following the reopening of Geneva, 24-hour PM_{10} levels exceeded 150 $\mu g/m^3$ on 10 occasions with a single day high at 223 (Figure 2).

During the winter of 1985/86, a random sample of county residents indicated that most residents thought that air quality was a serious problem and 29 per cent indicated that they had one or more members of their family who had health problems that were aggravated by air pollution.[28] During the winter of 1987/88, following the closure and subsequent reopening of the steel mill, there was much local discussion about the contrast in air quality. The frequency and severity of respiratory illnesses were commonly perceived to have dropped when the mill was shut down, and then dramatically increased when it reopened. Newspaper articles, letters to the editor, and testimonials in public meetings often reflected this perception by many in the community.

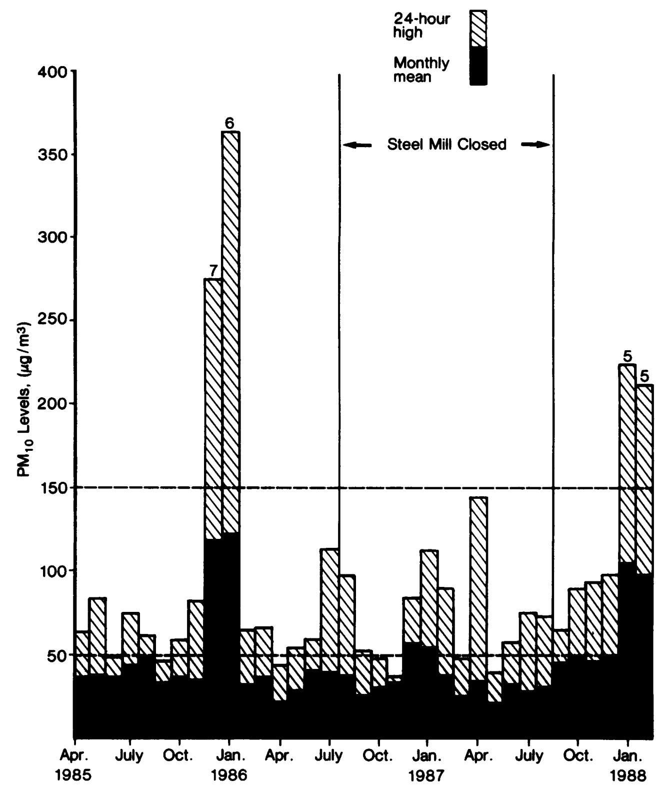

FIGURE 2—Monthly Mean and 24-Hour High PM_{10} (fine particulate pollution) Levels, Utah Valley, April 1985–January 1988

Health Data

Hospital admissions data for respiratory-related illnesses were collected from April 1985 through February 1988. There were only four hospitals in the county. Data were collected from three of them that together had 579 beds. The other hospital in the County had only 20 beds, no pediatrics unit, no pulmonologist on its staff, and rarely provided inpatient care for respiratory illnesses.

A preliminary study of diagnosis-related groups (DRGs)[29] at Utah Valley Regional Medical Center indicated that DRGs 79, 80, and 81 (Respiratory Infections and Inflammations), DRGs 85 and 86 (Pleural Effusion), DRG 87 (Pulmonary Edema and Respiratory Failure), DRG 88 (Chronic Obstructive Pulmonary Disease), DRGs 92 and 93 (Interstitial Lung Disease), and DRGs 99 and 100 (Respiratory Signs and Symptoms) accounted for only 4.9, 0.6, 1.6, 3.3, 0.8, and 5.8 per cent of the collected cases, respectively. Initial comparative statistical analysis and regression analysis did not reveal any association between the closing and subsequent reopening of Geneva or PM_{10} levels and hospital admissions for any of these DRGs individually or collectively.

The bulk of the respiratory illness (83 per cent) were for the six DRGs that included 89, 90, and 91 (Simple Pneumonia and

Pleurisy) and 96, 97, and 98 (Bronchitis and Asthma) with 42 and 41 per cent of the cases, respectively. As a result, this analysis focuses on hospital admissions where the principal diagnosis was classified within one of these six DRGs.

Monthly admissions data for these six DRGs were compiled for each of the three hospitals. Records for outpatient and emergency admissions were not complete or consistent for the full time period. Therefore, only inpatient data were used in this analysis. Accurate records for Mountain View Hospital were available for the time periods April 1985 through September 1986 and January 1987 through February 1988. Accurate inpatient records for the other two hospitals were available from April 1985–February 1988.

Analysis Conducted

Utah Valley Regional Medical Center's admissions were sorted into in-county and out-of-county admissions. Both Utah Valley Regional Medical Center and American Fork Hospital are located within the central urban area of the county, near the major sources of pollution. The primary analysis used the combined Utah Valley Community Hospital in-county admissions and American Fork Hospital admissions as an indicator of the level of relatively severe respiratory illness in the urban area of the county.

Three other sets of hospital admissions data were used as control variables: "all-other" admissions from Utah Valley Regional Medical Center and American Fork Hospital, excluding in-county admissions for pneumonia, pleurisy, bronchitis and asthma; out-of-county admissions to Utah Valley Regional Medical Center for pneumonia, pleurisy, bronchitis, and asthma; and admissions to Mountain View Hospital in Payson for the same illnesses.

Hospital admission levels were compared across months with different levels of particulate pollution as measured by PM_{10}. Admission levels were also compared across comparable periods of time when the steel mill was open, closed, and then reopened. Finally, monthly hospital emissions were regressed on PM_{10} levels and weather variables obtained at Brigham Young University.[30]

Results

Comparative Analysis

As can be seen in Figure 2, there was considerable variability in PM_{10} levels in the county over the study period. During those months when exceedances of the 24-hour PM_{10} standard of 150 $\mu g/m^3$ occurred, the number of admissions for children, 0–17 years of age, was nearly triple the number of admissions for months with no exceedances (Table 1). In adults, admissions were approximately 44 per cent higher during the months when exceedances occurred.

During months when the arithmetic mean PM_{10} levels were equal to or greater than 50 $\mu g/m^3$, children admissions were nearly double than when the average PM_{10} levels were less than 50 $\mu g/m^3$. Adult admissions were increased by approximately 47 per cent.

The above comparisons were complicated by the fact that the months with especially high levels of particulate pollution were during the winter, and the reason for the high incidence of respiratory illness may be at least partly attributed to winter weather. The intermittent operation of the steel mill provided the opportunity to compare different winter seasons with marked differences in PM_{10} levels. Figure 2 demonstrates that when the steel mill was closed, PM_{10} levels were relatively low. One concern about making observations pertaining to these time periods is that the winter when the Geneva steel mill was closed may have had relatively good weather conditions and limited conditions of stagnant air. Weather data indicated that temperatures fell below zero on only two occasions throughout the study period, both in January of 1988 when they fell as low as $-1°$ and $-7°$. Snowfall during this time period for 1985/86, 1986/87, and 1987/88 totaled only 45.5, 33.5 and 27.5 inches, respectively.[30]

The National Weather Service computes an air stagnation or clearing index for valleys in Western Utah, including Utah Valley.[31] The index ranges from 0–1000 with lower values indicating more stagnant air. When the index is less than 200 pollution dispersal is "very poor" and weather conditions are such that air pollution potential is high. The month with the lowest average clearing index occurred during the winter the mill was closed. The average clearing index for the winter period of December–February for 1985/86, 1986/87, and 1987/88 was 388, 345, and 367, respectively, and the number of days when the index was below 200 for the same time periods equalled 47, 54, and 47, respectively.[32] Based on this index the air was relatively more stagnant and had higher air pollution potential during the winter when the mill was shut down than the previous or following winters.

Table 2 presents comparisons of hospital admissions be-

TABLE 1—Comparisons of Monthly Average Number of Hospital Inpatient Admissions for Utah Valley Regional Medical Center and American Fork Hospital across Months with Different Levels of PM_{10}[a]

Months Included	Number of Months Included	Mean PM_{10} Level for Months Included	Mean High PM_{10} Level for Months Included	Bronchitis and Asthma Ages 0–17	Bronchitis and Asthma Age 18+	Simple Pneumonia and Pleurisy Age 0–17	Simple Pneumonia and Pleurisy Age 18+	Subtotal Ages 0–17[b]	Subtotal Age 18+[b]	TOTAL[b]
All months	35	45.8 (4.3)	94.7 (11.9)	12.5 (1.6)	17.5 (1.0)	12.0 (1.5)	22.7 (1.6)	24.5 (2.8)	40.2 (2.3)	64.7 (4.5)
Months when 24-hour $PM_{10} < 150$ $\mu g/m^3$	31	37.5 (1.6)	72.3 (4.4)	10.5 (1.2)	16.9 (1.0)	9.9 (1.1)	21.4 (1.3)	20.4 (1.9)	38.3 (2.0)	58.6 (3.5)
Months when 24-hour $PM_{10} > 150$ $\mu g/m^3$	4	110.3 (5.5)	268.5 (35.0)	27.8 (6.7)	22.3 (2.9)	28.3 (4.6)	33.0 (8.1)	56.0 (11.1)	55.3 (10.0)	111.3 (14.0)
Months when mean $PM_{10} < 50$ $\mu g/m^3$	27	35.1 (1.3)	68.7 (4.6)	10.1 (1.3)	16.5 (1.1)	10.2 (1.2)	19.8 (1.2)	20.3 (2.1)	36.3 (2.0)	56.7 (3.9)
Months when mean $PM_{10} \geqq 50$ $\mu g/m^3$	8	82.0 (11.0)	182.5 (36.4)	20.4 (4.4)	20.8 (1.8)	18.0 (4.5)	32.5 (3.9)	38.4 (8.5)	53.3 (5.1)	91.6 (10.0)

[a]Standard errors at the means are presented in parentheses.
[b]Total may not sum up exactly due to rounding error.

tween fall and winter periods when the steel mill was open, closed, and reopened. During the winter months from December to February, hospital admissions for children were approximately three times as high when the steel mill was open than when it was closed. Even during the Fall months (September–November) when no exceedances for the 24-hour primary health standard occurred, children admissions for bronchitis and asthma were approximately twice as high when the steel mill was open. Adult hospital admissions were not as obviously associated with the reductions of PM_{10} that accompanied the closure of the steel mill. There was, however, a notable increase in adult admissions following the reopening of the mill.

Regression Analysis

The results of some of the regression models are presented in Table 3. Model 1 regresses total monthly hospital admissions for pneumonia, pleurisy, bronchitis, and asthma on current and lagged PM_{10} levels. All lagged variables simply refer to the previous month's value. The results demonstrate a strong correlation between admissions and PM_{10}. In fact, 59 per cent of the variance in monthly admissions for these respiratory illnesses is explained by current and lagged monthly mean PM_{10} levels alone.

In Model 2, current and lagged mean low temperature variables were also included. This relatively simple linear model with only PM_{10} and temperature variables explains 83 per cent of the variance in total hospital admissions for these respiratory illnesses. The correlation between mean PM_{10} levels, mean low temperatures and hospital admissions is particularly striking when actual admissions and estimated admissions based on Model 2 are plotted together over time (Figure 3). Models 3–14 repeat the analysis done in Models 1 and 2 for total adult admissions, total children admissions, adult admissions for pneumonia and pleurisy, children admissions for pneumonia and pleurisy, adult admissions for bronchitis and asthma, and children admissions for bronchitis and asthma.

Autocorrelated errors exist with some of the models, particularly those with only PM_{10} levels as independent variables. This autocorrelation, however, is largely eliminated when weather variables are included. For example, the Durbin-Watson D statistic is 1.0 for Model 1 and 1.6 for Model 2. It is 1.3 for Model 3 and 2.0 for Model 4. There is also collinearity between PM_{10} levels and temperature. The correlation coefficient between the mean low temperature and monthly mean PM_{10} levels equals −0.32. This collinearity complicates the analysis and makes specific best point estimators of the correlation coefficients difficult to estimate. However, Model 2 was reestimated using a nonlinear quasi-Newton iterative procedure which gave identical regression coefficients with somewhat smaller standard-errors.

Numerous other regression models were estimated that included snowfall, rainfall, evaporation, monthly mean temperatures, and mean high temperatures. The weather variable that was consistently most highly correlated with admissions was the mean low temperature. Regressions that used PM_{10} levels lagged for two months, and dummy variables that indicated the opening and closing of the steel mill and inversion seasons were also tried. Even with the inclusion of these other variables, strong, positive, correlations between hospital admissions and PM_{10} levels remained. Regression models were also estimated with monthly 24-hour high PM_{10} levels used as independent variables. The results were similar to those in Models 1–14 as presented in Table 3, but 24-hour high PM_{10} levels were generally not as strongly correlated with admissions as were the mean PM_{10} values.*

Analysis with Control Variables

Neither comparative analysis nor regression analysis revealed any associations between the control variables and PM_{10} levels or the closing and reopening of the steel mill. "All-other" admissions that excluded in-county admissions for pneumonia, pleurisy, bronchitis, and asthma averaged 1,562 per month and appeared to be declining slightly over the study period. No seasonal variability nor any association with PM_{10} levels or the closing and reopening of the mill was observed. Monthly "all-other" admissions regressed on PM_{10} levels and temperature variables (Models 15 and 16 in Table 3) showed no significant correlation with PM_{10} levels.

Out-of-county hospital admissions to Utah Valley Regional Medical Center and admissions to Mountain View Hospital in Payson were regressed on PM_{10} levels and temperature variables. Models 17 and 18 in Table 3 present the results of the regressions for total out-of-county admissions for pneumonia, pleurisy, bronchitis, and asthma. The same regressions were also run on out-of-county and Mountain View Hospital with admissions broken down by adults, children, and respiratory illnesses, as done in Models 1–14.

*Data available upon request to author.

TABLE 2—Comparisons of Hospital Inpatient Admissions for Utah Valley Regional Medical Center and American Fork Hospital across Time Periods with Geneva Steel Mill Open and Closed

Year	Steel Mill Open?	Mean PM_{10} Level for Months Included	Mean High PM_{10} Level for Months Included	Bronchitis and Asthma Ages 0–17	Bronchitis and Asthma Age 18+	Simple Pneumonia and Pleurisy Ages 0–17	Simple Pneumonia and Pleurisy Age 18+	Subtotal Ages 0–17	Subtotal Age 18+	TOTAL
				Winter Months (December–February)						
1985/86	yes	90	235	78	75	76	73	154	148	302
1986/87	no	51	96	23	67	32	83	55	150	205
1987/88	yes	84	177	78	65	71	126	149	191	340
				Fall Months (September–November)						
1985	yes	35	63	49	46	20	51	69	97	166
1986	no	31	47	23	48	25	60	48	108	156
1987	yes	47	83	55	46	24	66	79	112	191
				Fall and Winter (September–February)						
1985/86	yes	63	149	127	121	96	124	223	245	468
1986/87	no	41	71	46	115	57	143	103	258	361
1987/88	yes	66	130	133	111	95	192	228	303	531

TABLE 3—Sample Results of Multiple Regression Analysis

Model	Dependent Variable: Monthly Admissions	Regression Coefficients[a] Constant	PM_{10} Mean	Lagged PM_{10} Mean	Low Temperature	Lagged Low Temperature	R^2
1	Total	21.18	0.357	0.599	—	—	.59
		(7.1)	(.14)	(.15)			
2	Total	95.54	0.119	0.339	−0.351	−0.929	.83
		(12.8)	(.11)	(.11)	(.30)	(.31)	
3	Total Adult	25.31	0.150	0.175	—	—	.26
		(4.9)	(.09)	(.10)			
4	Total Adult	73.65	−0.016	0.017	−0.347	−0.486	.64
		(9.4)	(.08)	(.08)	(.22)	(.23)	
5	Total Child	−4.14	0.207	0.425	—	—	.67
		(4.0)	(.08)	(.08)			
6	Total Child	21.89	0.135	0.321	−0.004	−0.443	.75
		(9.7)	(.08)	(.08)	(.23)	(.24)	
7	Pn/Pl Adult	14.57	0.139	0.034	—	—	.19
		(3.5)	(.07)	(.07)			
8	Pn/Pl Adult	46.84	0.020	−0.063	−0.305	−0.252	.54
		(7.3)	(.06)	(.06)	(.17)	(.18)	
9	Pn/Pl Child	−1.50	0.112	0.183	—	—	.53
		(2.5)	(.05)	(.05)			
10	Pn/Pl Child	15.49	0.086	0.095	0.196	−0.487	.72
		(5.3)	(.04)	(.05)	(.13)	(.13)	
11	Br/As Adult	10.74	0.011	0.140	—	—	.36
		(2.0)	(.04)	(.04)			
12	Br/As Adult	26.81	−0.037	0.081	−0.042	−0.234	.59
		(4.3)	(.04)	(.04)	(.10)	(.11)	
13	Br/As Child	−2.63	0.094	−0.241	—	—	.60
		(2.5)	(.05)	(.05)			
14	Br/As Child	6.40	0.049	0.226	−0.201	0.044	.64
		(6.5)	(.05)	(.06)	(.15)	(.16)	
15	All-Other	1586	−0.050	−0.604	—	—	.02
		(46)	(.9)	(1.0)			
16	All-Other	1482	0.840	−0.798	5.904	−4.069	.15
		(120)	(1.0)	(1.0)	(2.8)	(2.9)	
17	Out-of-County Total	15.09	−0.047	−0.006	0.123	−0.264	.43
		(2.9)	(.02)	(.03)	(.07)	(.07)	
18	Mountain View Total	33.38	−0.013	−0.041	0.073	−0.474	.46
		(6.8)	(.05)	(.06)	(.16)	(.16)	

[a]The absolute value of the standard errors is provided in parentheses.
Pn/Pl=pneumonia/pleurisy
Br/As=bronchitis/asthma

Although Payson is located in the county and should be similarly influenced by contagious illness, it is over 32 kilometers from the major sources of pollution and should not be as influenced by monitored levels of PM_{10}.

The regressions using out-of-county and Mountain View Hospital admissions are limited by the fact that only about 15 per cent of Utah Valley Regional Medical Center admissions are out-of-county, and Mountain View Hospital's data are missing for the months of October, November, and December of 1986. The results indicated that there was significant correlation between the mean low temperature lagged variable similar to those in the earlier regressions. There was no positive correlation between out-of-county or Mountain View Hospital admissions and PM_{10} levels, however.

Discussion

The results indicated that hospital admissions for respiratory illnesses were strongly associated with PM_{10} levels. This association is much stronger for children than adults, and somewhat stronger for bronchitis and asthma than for pneumonia and pleurisy. These associations were particularly strong with monthly lagged variables suggesting that the health effects of particulate pollution are cumulative and that it takes time before they are manifested in inpatient hospital admissions data.

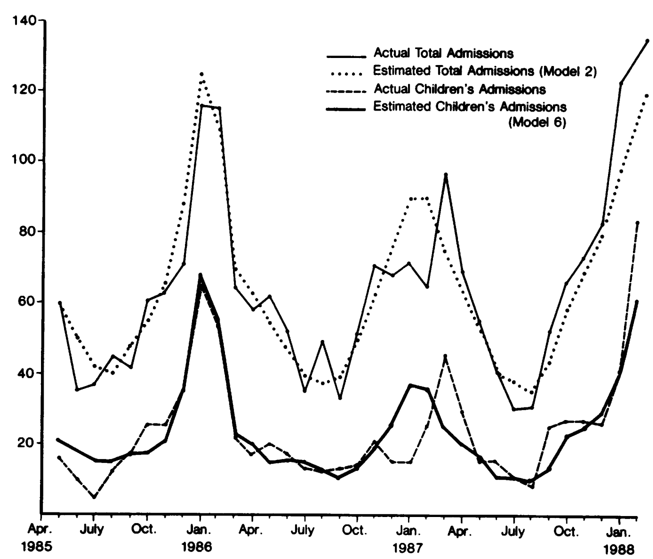

FIGURE 3—Actual and Estimated Hospital Admissions, April 1985 through January 1988, Utah Valley

Also, increased admissions for children are observed even for months when PM_{10} did not exceed 150 $\mu g/m^3$, suggesting that this standard may not be adequate protection for some children.

There are several concerns about these observations. One concern is that if increases in contagious illnesses such as influenza by chance coincided with periods of high PM_{10} levels, particularly during the winters when the steel mill was open, then the observed correlation between PM_{10} and admissions may be spurious. It would be expected, however, that if this were the case, the same correlation would be found in hospital admissions from neighboring counties or communities unaffected by Utah Valley's principal sources of pollution. No such correlation was found for out-of-county admissions to Utah Valley Regional Medical Center or to Mountain View Hospital in nearby Payson. Nor was such correlation found between PM_{10} levels and non-respiratory hospital admissions.

Another concern is that often levels of several air pollutants rise and fall in concert. PM_{10} may be a surrogate for other air pollutants with which it is temporarily associated. Two pollutants that may have had similar impacts on respiratory illnesses during the study period are total suspended particulates and ozone. Because PM_{10} measures only relatively small particles of particulate pollution, and because it is the smaller particles that are expected to pose the greatest health risks, it is considered the most appropriate measure of particulate pollution as it relates to respiratory health.[1] Regression models estimated with monthly mean total suspended particulate levels used as independent variables yielded results similar to Models 1–14 presented in Table 3 which used PM_{10}. The correlations between admissions and total suspended particulates were generally not as strong as those between admissions and PM_{10}.

There was no evidence that suggested that PM_{10} was serving as a surrogate for ozone pollution. The only times ozone pollution in Utah Valley rose to levels of any consequence was in the summer months during hot sunny days, whereas the periods of high levels of PM_{10} and hospital admissions for respiratory illness occurred mostly during the winter months when the steel mill was in operation. The results of this study suggest that the dominant pollution in terms of its impact on respiratory health in Utah Valley is particulate pollution and that PM_{10} is a better indicator than TSP.

Finally, the association between respiratory illness and particulate pollution found in this study is relatively large as compared with some previous studies.[20–22,33] This relatively strong association can be explained in part because PM_{10} is a better indicator of particulate pollution as it relates to respiratory health than previously used indicators.[1] Also, because Utah Valley experiences relatively high levels of particulate pollution, yet has an extremely low portion of its population that smoke, particulate pollution is likely a relatively large contributor to respiratory disease in the county.

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